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Ground Shock Profiles for an Accidental Explosion at the Proposed Large Rocket Test Facility at Arnold Engineering Development Center

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This study is an assessment of the ground shock in profile which may be generated in the event of an accidental explosion at the proposed Large Rocket Test Facility (LRTF) at Arnold Engineering Development Center (AEDC). The assessment is accomplished by using the results of a previous study by the author and by reviewing existing ground motion data at depth, for sites with similar geology to expected conditions at AEDC. Empirical relationships are developed from these data and the relationships are used to predict the ground motion in profile. As indicated above, the surface ground motion predictions were developed in a previous study by the author and rely upon an existing relationship (Lipner et al.) to predict surface velocity. Empirical relationships developed in the course of the previous study, predict surface acceleration and displacement. The empirical relationships developed in this study are used to predict acceleration, velocity, and displacement at depth. The ground motions are presented in table form

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Preface

The work reported herein was conducted by Lawrence Livermore National Laboratory (LLNL), Livermore, CA, 94550, under MIPR number FY7483-83-0008 for the Director of Technology (DOT), Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), and Arnold Air Force Station, Tennessee, during the period of December 1986 to July 1987. The Project Manager was Mr. Carlos Tirres, AEDC/DOTF. Ray Pierce was the Project Manager for LLNL. Bob Murrary was the Project Leader for this task, and Don Bernreuter provided consultation and technical direction. The manuscript was submitted for publication on December 14, 1987.

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Abstract

This study is an assessment of the ground shock in profile which may be generated in the event of an accidental explosion at the proposed Large Rocket Test Facility (LRTF) at Arnold Engineering Development Center (AEDC). The assessment is accomplished by using the results of a previous study by the author and by reviewing existing ground motion data at depth, for sites with similar geology to expected conditions at AEDC. Empirical relationships are developed from these data and the relationships are used to predict the ground motion in profile. As indicated above, the surface ground motion predictions were developed in a previous study by the author and rely upon an existing relationship (Lipner et al.) to predict surface velocity. Empirical relationships developed in the course of the previous study, predict surface acceleration and displacement. The empirical relationships developed in this study are used to predict acceleration, velocity, and displacement at depth. The ground motions are presented in table form and as profile plots. The results of this study and previous studies by the same author are intended to be used for evaluating the siting of the LRTF.

Introduction

This study is an extension of two earlier studies (Refs. 1 and 2), which developed empirical estimates of ground motions in the event of an accidental explosion at the proposed Large Rocket Test Facility (LRTF) or the existing J5 rocket development test cell on the Arnold Engineering Development Center (AEDC), Arnold Air Force Station, Tennessee. In the first study, the empirical relationships were developed for LRTF constructed with no earth covering. Other studies (Ref. 3) conducted at that time indicated that the fragment/debris, blast overpressures, and blast focusing generated from an accidental explosion were disadvantageous.

Earth covering of the proposed LRTF would reduce or eliminate damage due to fragment/debris, blast overpressure, and focusing, but, is disadvantageous because it would increase the effects of ground shock. This concern led to the second study, which evaluates ground motions for an earth-covered LRTF. An evaluation of cost and operational concerns has led to a preferred choice of a surface constructed LRTF but with a barometric well sited at depth some distance from LRTF. Concern over siting of the barometric well led to this study, which evaluates ground motion at depth from an accidental explosion at a surface-sited LRTF.

As indicated, the results of this study can be used to estimate ground motions at depth in the event of an accidental explosion at the proposed LRTF.

Site Description

The site information was provided by E. M. Caldwell from AEDC and J. Kent Lominac, Area Engineer with the U.S. Army Corps of Engineers. Caldwell furnished the surface information by making available the USDA Soil Survey for Coffee County, Tennessee. Lominac furnished the subsurface information by making available various soil-boring investigations conducted by the U.S. Army Corps of Engineers and Dames & Moore.

Arnold Air Force Station is in south-central Tennessee, approximately 70 miles southeast of Nashville. The site for the proposed LRTF facility at AEDC is located on the northeast side of the Retention Reservoir, about one-half mile northwest of the J4 and J5 rocket development test cells (Ref. 4) and approximately one mile northwest of the Aeropropulsion Systems Test Facility.

Geologically, AEDC is located in the Highland Rim Physiographic Province near the drainage divide of the Duck and Elk Rivers. The Central Basin is west of AEDC; east of AEDC is the transition to the Cumberland Plateau, which is followed by the Valley, the Ridge, and the Blue Ridge Provinces.

Surface elevations range from about 960 ft to 1200 ft. AEDC is at approximately 1100 ft elevation.

The overburden at AEDC is primarily limestone/dolomite residual material formed by weathering of in situ bedrock. The soil can contain large amounts of residual chert, occurring as angular blocks and fragments. The U.S. Army Corps of Engineers soil-boring investigations indicate that the chert can be so concentrated as to be mistaken for bedrock. The overburden also contains sand, gravel, and silt mixtures.

The first sound rock occurs at a fairly uniform elevation ranging from 1038 to 1043 ft. Approximately 28 ft of hard, dense, light gray, massive, siliceous limestone exists, containing some cavities filled with calcite crystals. The limestone has tested out sound and unweathered except for approximately horizontal bedding planes in the first 5 to 15 ft. These planes, or seams, vary in thickness from 2 to 18 in.; they are evidenced by leaching and solution oxidation discoloration.

Below the limestone, a 19- to 21-ft-thick shale formation occurs (Chattanooga Shale) at a fairly uniform elevation ranging from 1011 to 1014 ft. The shale is hard, dense, black, and cemented. It appears to be extremely fissile at the top and fairly thick-bedded at the bottom.

Underlying the shale is a shaley limestone, identified as the Catheys Formation of the Trenton Group. This shaley limestone is hard, dense, and light-to-dark mottled gray in color.

A static groundwater level has been measured 6 to 18 ft below ground surface. Dames & Moore of Atlanta reported that the near-surface groundwater resulted from a combination of shallow water conditions, perched water, leakage from underlying artesian aquifers, and surface accumulation. Groundwater investigations carried out by the U.S. Army Corps of Engineers identified the pervious zone at the top of the first sound rock as an artesian aquifer.

Surface Burst Ground Shock Phenomenology

Explosive detonations produce motions and stresses in the earth's surface. These motions and stresses are collectively called ground shock. The ground shock induced by explosive detonations depends on the explosive type, design, yield, the height-of-burst (HOB) or depth-of-burst (DOB), and site characteristics. Three general types of ground shock have been defined (Ref. 5):

<u>Airblast-Induced (AI) Ground Shock</u>--air pressure waves are generated by an explosion which is "vented" to the surface. These pressure waves push upon the ground surface and induce ground stresses and motions.

<u>Direct-Induced (DI) Ground Shock</u>--surface or underground explosions produce explosive gases. These gases push against the surrounding medium and induce ground stresses and motions.

<u>Crater-Induced (CI) Ground Shock</u>--the explosive energy displaces the medium. As the earth material is thrown outward, it pushes against the adjacent media, inducing ground stresses and motions.

For a surface burst, the phenomenology at early-time is dominated by airblast effects. The airblast arrives first, causing air slap on the ground surface. This produces strong downward and outward motions. Compressional motions follow and are associated with the DI/CI ground shock. These compressional motions are a dominant late-time phenomena, producing large upward and outward low-frequency ground motion. The range and magnitude of the AI or DI/CI ground motions are dependent on the yield, HOB, and site conditions. It should be noted that, close-in and at early-time, ground motion will be AI or DI/CI, but generally not both.

With increasing range from the burst point, the relatively simple motions become a complex wavetrain of surface waves. These surface waves appear to be relatively insensitive to blast geometry. As the horizontal distance from detonation increases, the complex wavetrain of surface waves is similar for a buried cratering burst, for a surface burst, or for an air burst.

Ground-energy coupling is dependent on several factors beside yield, of which the most significant are blast design characteristics, HOB, and site properties. Blast design characteristics include blast source concentration (spherical/point source, directed source, line source, etc.) and type of blast. The design of the blast source (i.e., concentration) aids in directing the energy. The type of blast also affects ground-energy coupling. High explosive sources (TNT, PETN, PBX, etc.) have been found to be approximately twice as efficient as a nuclear source in generating airblast; conventional explosives convert most of the energy into blast and shock while a nuclear source expends a portion of its energy thermally.

The effect of HOB is a major contributor in ground-energy coupling. As HOB increases, AI effects become more dominant, with DI/CI effects diminishing. In general, as HOB increases and AI effects dominate, the close-in early-time ground motion is maximum in the vertical direction. Alternately, as DI/CI effects dominate, the close-in early-time ground motion is maximum in the horizontal direction.

Because many site property effects influence ground-energy coupling, these effects can only be broadly generalized. For non-homogeneous geological layering, stiffer layers transmit shock faster. Thus, ground shock in a stiffer layer at depth can outrun the airblast conditions still in existence near the surface. Layering and stiffness can also have the effect of strengthening ground shock by wave reflection.

As indicated, the ground shock will be a result of either AI or DI/CI effects and can be broken down into three regions of disturbance types: superseismic, transseismic, and subseismic (Ref. 6).

Media, such as soil, rock, and water, propagate wave disturbances at velocities that are functions of the material properties. At the ground surface, three types of wave disturbance produce the majority of the ground motion; they are identified as primary (p), secondary (s), and Rayleigh waves. The p- and s-waves are also known as body waves and are, respectively, compressional and shear in nature. Rayleigh waves are also known as surface waves. The presence of all three waves is not limited to the surface, but the Rayleigh wave attenuates rapidly with depth. Flint and Skinner further describe the manner in which these waves deform solids (Ref. 7). The speeds of propagation (C) of these waves are related as follows:

$$C_p > C_s > C_R ,$$

where C_p is the p-wave propagation velocity, C_s is the s-wave propagation velocity, and C_R is the Rayleigh wave propagation velocity. The above relationship indicates a point at or just beneath the surface is first affected by the p-wave arrival, second by s-wave arrival, and finally by arrival of the Rayleigh wave. At the surface, the p- and s-waves decay faster with range than does the Rayleigh wave.

The superseismic region is defined as that region where airblast velocity exceeds all wave propagation velocities:

$$U > C_p > C_s ,$$

where U is the airblast velocity. Since U is larger than C_p or C_s, no disturbance exists ahead of the airblast, and ground shock trails airblast.

When airblast shock velocity falls below the p-wave propagation velocity but still exceeds the s-wave propagation, the region is known as transseismic. In this region, compressional disturbances can propagate in the ground ahead of the airblast:

$$C_p > U > C_s .$$

When airblast velocity falls below the s-wave propagation, the subseismic case exists:

$$C_p > C_s > U .$$

For both transseismic and subseismic regions, compressional and shear disturbances can propagate through the ground ahead of the airblast shock. For that reason, they are often collectively referred to as the *outrunning region* to indicate that ground shock has outrun the airblast shock.

Several factors can influence or contribute to the complex nature of the surface waves at early- or late-time. One result of such influence or contribution could be refracted and reflected waves outrunning airblast shock when superseismic conditions would otherwise exist at the surface. Another could be the existence of superseismic conditions when outrunning conditions would otherwise exist at the surface.

Study Methodology

Competent ground shock prediction for a site can be obtained through the use of large-scale computer code modeling techniques. Simplified computer techniques are available (Ref.8), but have large uncertainties associated with them. Most of the techniques are based on some combination of data from theoretical studies and field test observations. These techniques approximate the complete environment that will result from disturbances arriving from all sources by superimposing air detonation, surface detonation, and contained detonation motion according to their relative time-phasing.

For this study, appropriate high-explosive (HE) events, which have geology similar to the AEDC site, were identified and the data used to develop empirical relationships to predicted expected ground motions at depth due to a surface detonation. A previous report (Ref. 1) predicts ground motions for the case of a surface explosion; this report concentrates on the conditions at depth resulting from a surface detonation.

As indicated in the discussion of ground shock phenomenology, site property effects influence ground-energy coupling. In general, stiffer layers transmit shock faster. The contacts between various geologic zones or a groundwater table serve as refraction boundaries. Ground shock is refracted from these boundaries as an upward-moving pulse. On the surface this is manifested by ground shock outrunning the airblast motion and at depth the ground shock outruns the surface expression.

AEDC has the general site condition of approximately 80 ft of wet (groundwater table [GWT] of about 12-18 ft), layered soil made up of clays, silts, and sands overlying limestone/dolomite.

Several HE events were identified as having geology comparable to AEDC. The first of these are the Distant Plain events (Refs. 9 & 10). These experiments were conducted at the Suffield Experiment Station in Alberta, Canada. There are two different geologies that exist at this experiment station. The first consists of 10 ft of silty clay overlying fine free-flowing sand. The depth to rock is about 200 ft. The water table is at 23 ft. The second site geology consists of saturated glacial till extending down to bedrock at about 100 ft.

The second set of HE events identified were the Prairie Flat tests (Ref. 11). These were HE tests also conducted at the Suffield Experiment Station.

The third set of HE events identified were the Flat Top tests (Ref. 10). These were HE tests conducted at the Nevada Test Site (NTS) on Frenchman Flats. The site consists of several hundred ft of dry, fine-grained silt and geologically does not compare well to AEDC or the Suffield Experiment Station. But, the scaled data agrees well with the Distant Plain and Prairie Flat results.

The final set of HE events identified were the Mine Shaft Series of tests known as Mine Under, Mine Ore, and Mineral Rock (Refs. 13 & 14). These tests were conducted outside Cedar City, Utah, and were specifically designed to investigate the phenomenon of outrunning ground motion.

Acceleration Prediction

The acceleration data collected is presented in Figs. 1 - 6. Least Squares Regression Analyses were performed on the data; the resulting relationships are indicated on the figures, where W is the yield in tons, R is the range in ft, and a is acceleration in g. In an earlier study (Ref. 1), relationships for predicting surface ground motion were explored. The recommended surface ground acceleration expressions were reported as follows:

$$a_v = 6.7 \times 10^6 \, (R/W^{1/3})^{-1.9} \qquad (1)$$

$$a_h = 1.7 \times 10^5 \, (R/W^{1/3})^{-1.6} \qquad (2)$$

where W is yield in kilotons, R is the range in ft, and a is acceleration in g. Table 1 presents the predicted ground acceleration with range and depth for a 50T TNT equivalent explosion at LRTF.

Velocity Prediction

The velocity data collected is presented in Figs. 7 - 14. Least Squares Regression Analyses were performed on the data; the resulting relationships are indicated on the figures, where W is yield in tons, R is the range in ft, and v is velocity in ft/sec. In the earlier study (Ref. 1), relationships for predicting surface ground motion were explored. The recommended surface ground velocity expressions were reported as follows:

$$v_v = (2W/1MT)^{1/2} \, (10{,}000 \text{ ft}/R)^{3/2} \qquad (3)$$

$$v_h = 0.55 \, (2W/1MT)^{1/2} \, (10{,}000 \text{ ft}/R)^{3/2} \qquad (4)$$

where R is the range in ft, W is the yield in tons, and v is the velocity in ft/sec. Table 2 presents the predicted ground velocity with range and depth for 50T TNT equivalent explosion at LRTF.

Displacement Prediction

The displacement data collected is presented in Figs. 15-22. Least Squares Regression Analyses were performed on the data; the resulting relationships are indicated on the figures, where W is the yield in tons, R is the range in ft, and d is displacement in ft. In an earlier study (Ref. 1), relationships for predicting surface ground motion were explored. The recommended surface ground displacement expression was reported as follows:

$$d_{max}/W^{1/3} = 1 \times 10^8 \, (R/W^{1/3})^{-2.8} \qquad (5)$$

where R is the range in ft, W is the yield in kilotons, and d is the displacement in inches. Table 3 presents the predicted ground displacement with range and depth for a 50T TNT equivalent explosion at LRTF.

Results

The near-surface and at-depth acceleration, velocity, and displacement ground motions for detonation of a 50T TNT equivalent explosion are listed in Tables 1, 2, and 3. It should be noted that these values are only a best guess of the ground motions which will be generated in the event of a 50T TNT equivalent accidental explosion at LRTF. Actual site conditions may cause values either higher or lower than those predicted. Noteworthy site conditions which can impact the ground motions generated are the site specific soil conditions and the structural configuration of LRTF. For example, if the facility includes a blast wall with foundation to depth, then more coupling of ground motion, particularly at the foundation base, will occur than indicated in this study. The use of a berm instead of a blast wall would serve the purpose of impeding air blast/debris without providing the potential of enhancing ground motion at depth. It must be remembered that ground motion at depth is of importance to the issue of placement of the buried barometric well. The best method of evaluating expected ground motions is to conduct site specific studies and identify the response of the AEDC Site. Figures 23 and 24 give the peak vertical and horizontal ground acceleration profiles, respectfully, for a 50T TNT equivalent surface explosion. Peak vertical and horizontal ground velocity profiles for a 50T TNT equivalent surface explosion are shown in Figs. 25 and 26. Profiles of vertical and horizontal ground displacement for a 50T TNT equivalent surface detonation at the proposed LRTF are shown in Figs. 27 and 28.

Recommendation

As discussed in the previous studies (Refs. 1 & 2), it is recommended that v = 2 ips (v = 0.167 fps) be used as a lower bound for an indication of structural damage. This correlates to a ground acceleration of 0.15 to 0.25 g. Table 2 gives ranges for the 2 ips ground velocity contour for a 50T TNT equivalent explosion. The range of the 2-ips contour should be examined when considering the siting of the proposed barometric well. Cost considerations need to be evaluated as to whether the barometric well should be sited further away, or adequately engineered to withstand the ground motions.

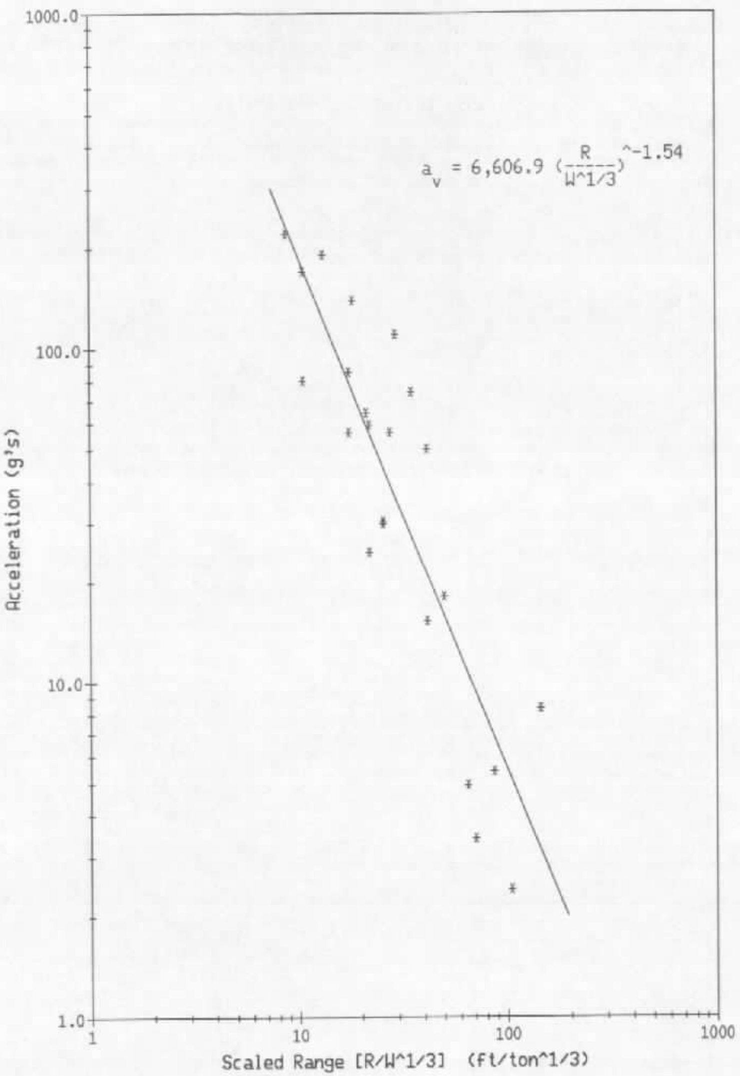

Figure 1. Peak Vertical Acceleration at 5 foot depth, from surface detonation.

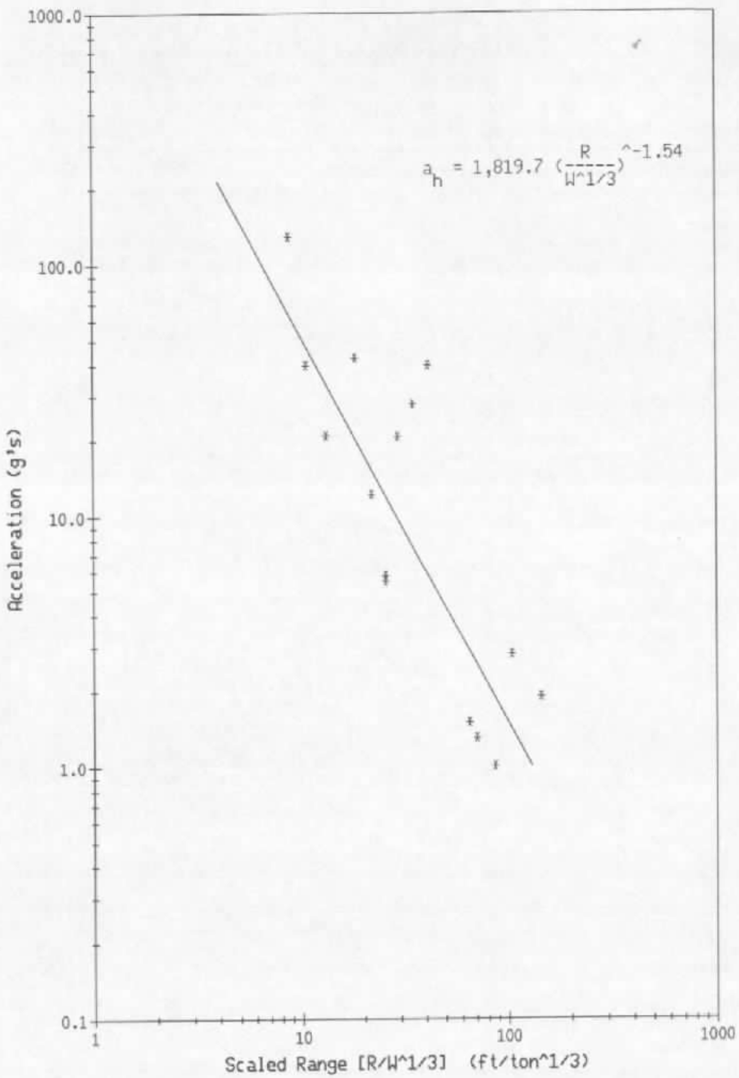

Figure 2. Peak Horizontal Acceleration at 5 foot depth, from surface detonation.

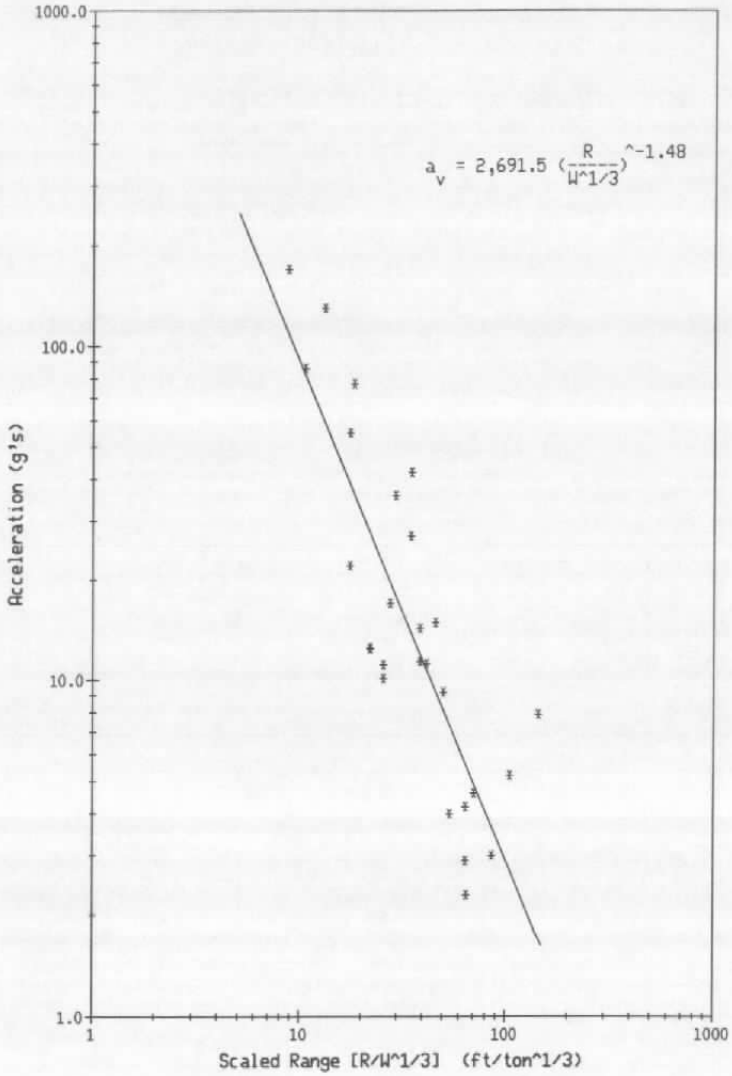

Figure 3. Peak Vertical Acceleration at 10 foot depth, from surface detonation.

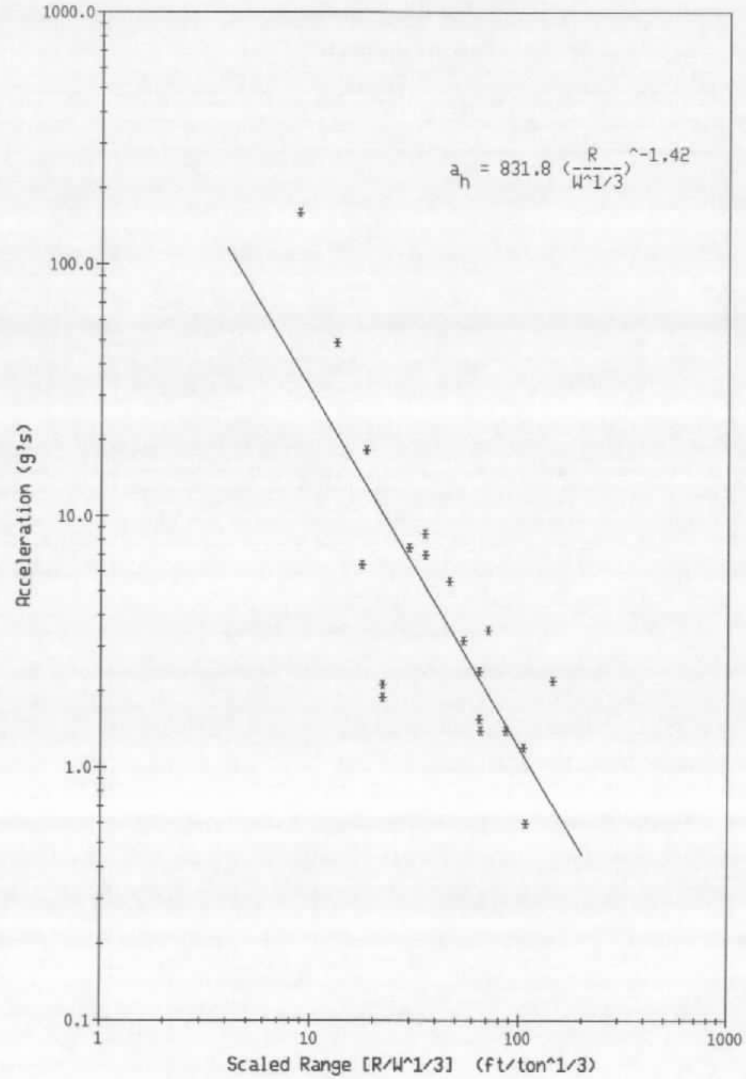

Figure 4. Peak Horizontal Acceleration at 10 foot depth, from surface detonation.

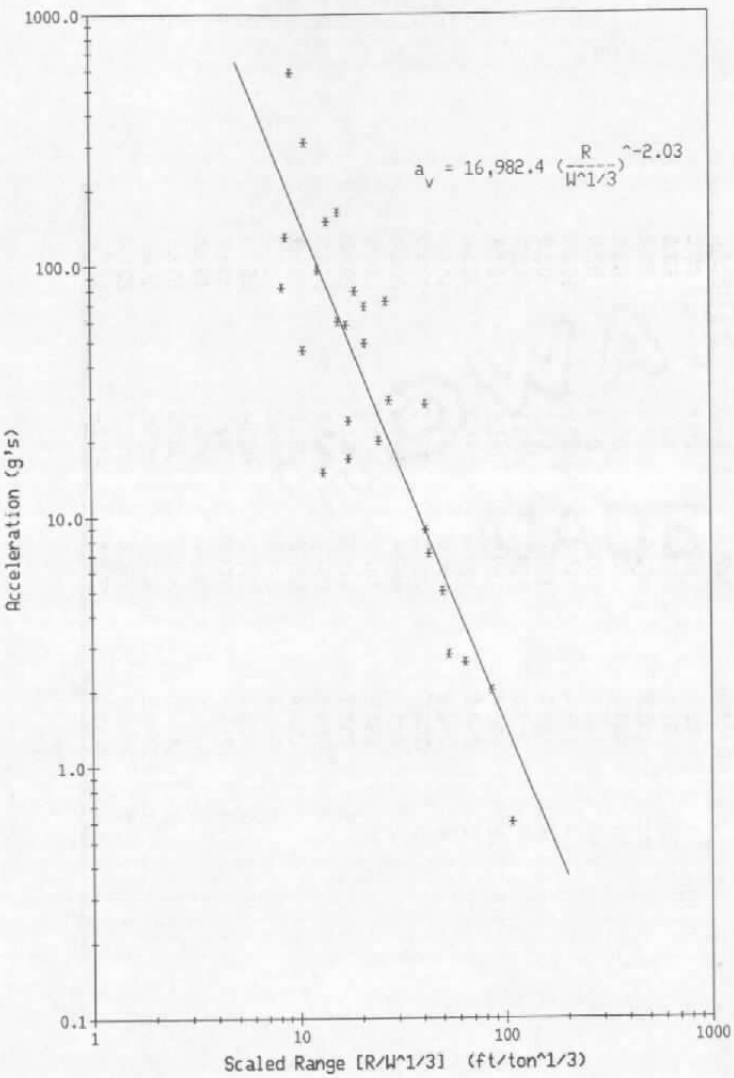

Figure 5. Peak Vertical Acceleration at 18 foot depth, from surface detonation.

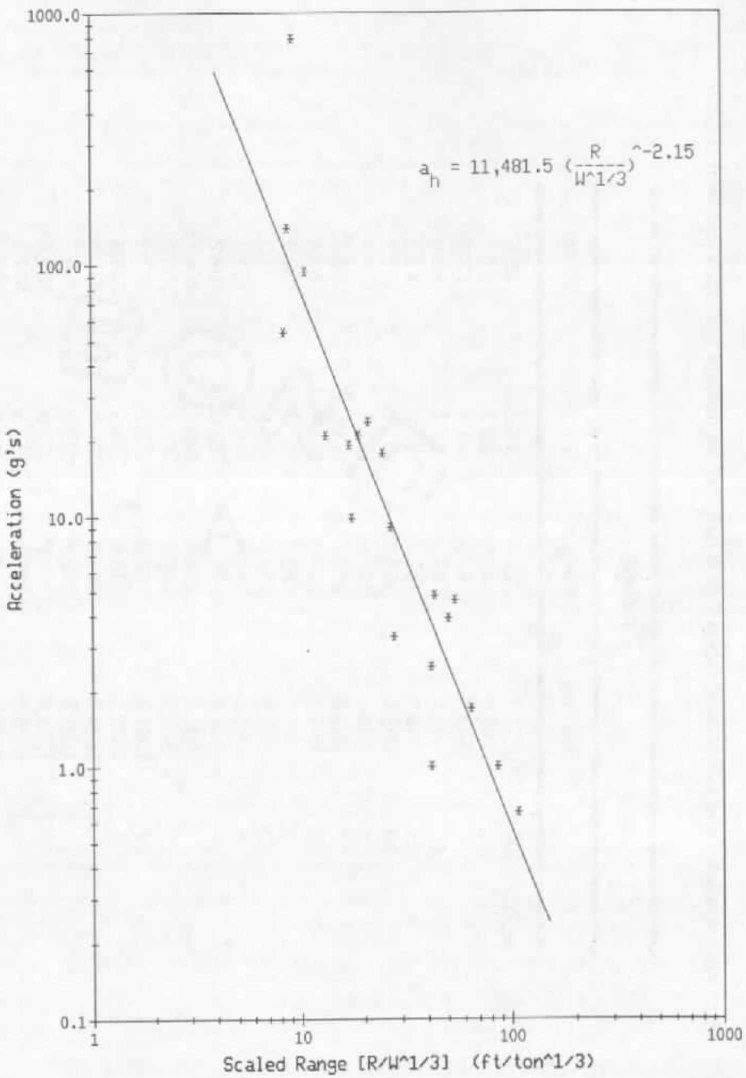

Figure 6. Peak Horizontal Acceleration at 18 foot depth, from surface detonation.

Table 1. Peak accelerations and associated ranges for a 50T TNT equivalent surface explosion at LRTF.

		RANGE (ft)			
		Surface	5 ft depth	10 ft depth	18 ft depth
a_v (g):	300.	71.7	27.4	16.2	26.9
	150.	103.2	43.0	25.9	37.9
	75.	148.6	67.5	41.4	53.3
	50.	184.0	87.8	54.4	65.0
	25.	265.0	137.7	87.0	91.5
	20.	298.0	159.2	101.1	102.1
	15.	346.7	191.9	122.8	117.7
	10.	429.2	249.7	161.5	143.7
	9.	453.7	267.4	173.4	151.4
	8.	482.7	288.7	187.8	160.4
	7.	517.9	314.8	205.5	171.3
	6.	561.6	348.0	228.1	184.8
	5.	618.2	391.7	258.0	202.2
	4.	695.2	452.8	300.0	225.7
	3.	808.9	545.8	364.3	260.0
	2.	1001.3	710.2	479.2	317.5
	1.	1442.1	1113.9	765.4	446.8
	.9	1524.3	1192.8	821.9	470.6
	.8	1621.8	1287.6	890.0	498.7
	.7	1739.9	1404.2	974.0	532.6
	.6	1886.9	1552.0	1080.9	574.6
	.5	2077.0	1747.1	1222.6	628.6
	.4	2335.8	2019.5	1421.6	701.6
	.3	2717.7	2434.3	1726.6	808.4
	.2	3364.1	3167.5	2270.7	987.2
	.15	3914.1	3818.1	2757.9	1137.5
	.1	4845.2	4968.1	3627.2	1388.9
	.05	6978.3	7792.3	5793.8	1954.2
a_h (g):	50.	59.4	38.0	26.7	46.2
	25.	91.5	59.6	43.5	63.8
	20.	105.2	68.9	50.9	70.7
	15.	126.0	83.1	62.3	80.8
	10.	162.3	108.1	82.9	97.6
	9.	173.4	115.8	89.3	102.5
	8.	186.6	125.0	97.0	108.3
	7.	202.8	136.3	106.5	115.2
	6.	223.4	150.6	118.8	123.8
	5.	250.3	169.6	118.8	123.8
	4.	287.8	196.0	158.0	149.5
	3.	344.5	236.3	193.5	170.9
	2.	443.8	307.4	257.4	206.4
	1.	684.5	482.2	419.4	284.9
	.9	731.1	516.3	451.7	299.2
	.8	786.9	557.4	490.8	316.1
	.7	855.4	607:8	539.2	336.3
	.6	941.9	671.8	601.0	361.3
	.5	1055.6	756.3	683.4	393.3
	.4	1213.6	874.2	799.7	436.3
	.3	1452.6	1053.8	979.2	498.8
	.2	1871.6	1371.1	1302.8	602.3
	.15	2240.3	1652.8	1595.4	688.5
	.1	2886.4	2150.6	2122.7	831.4
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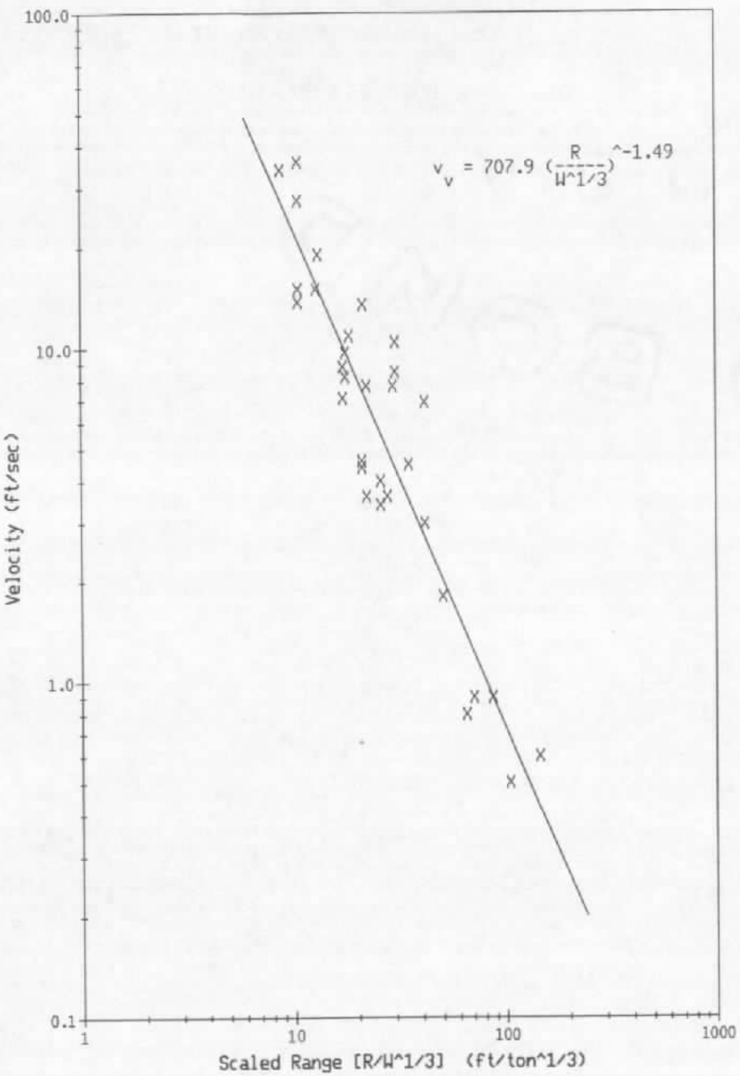

Figure 7. Peak Vertical Velocity at 5 foot depth, from surface detonation.

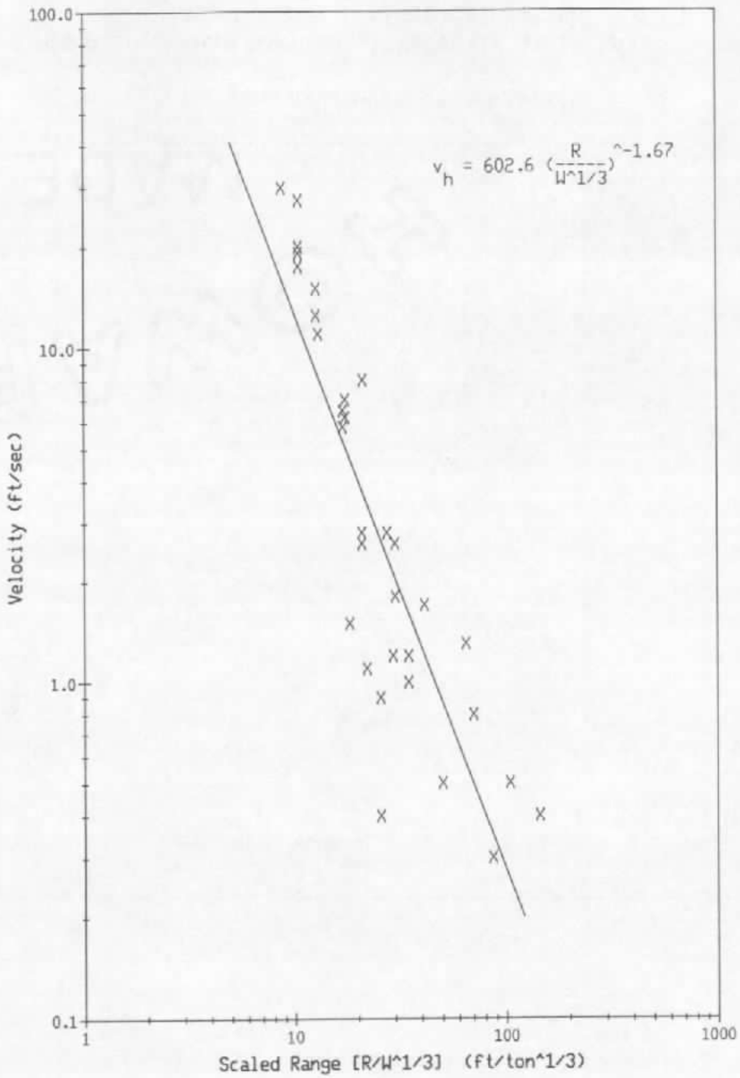

Figure 8. Peak Horizontal Velocity at 5 foot depth, from surface detonation.

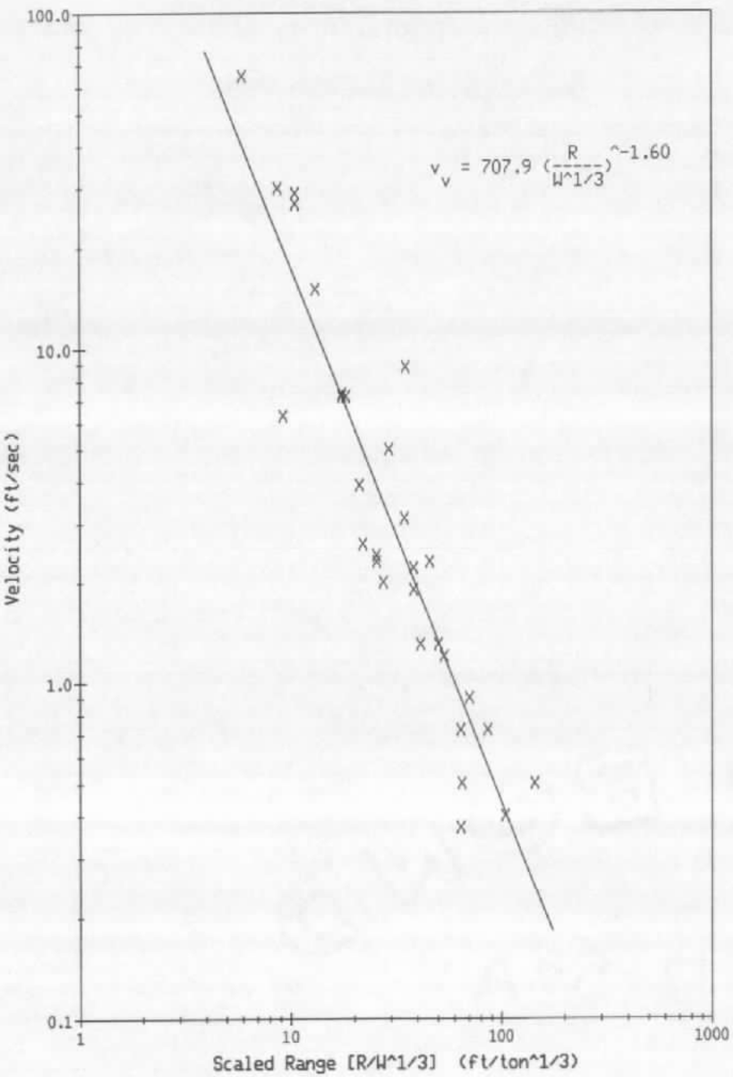

Figure 9. Peak Vertical Velocity at 10 foot depth, from surface detonation.

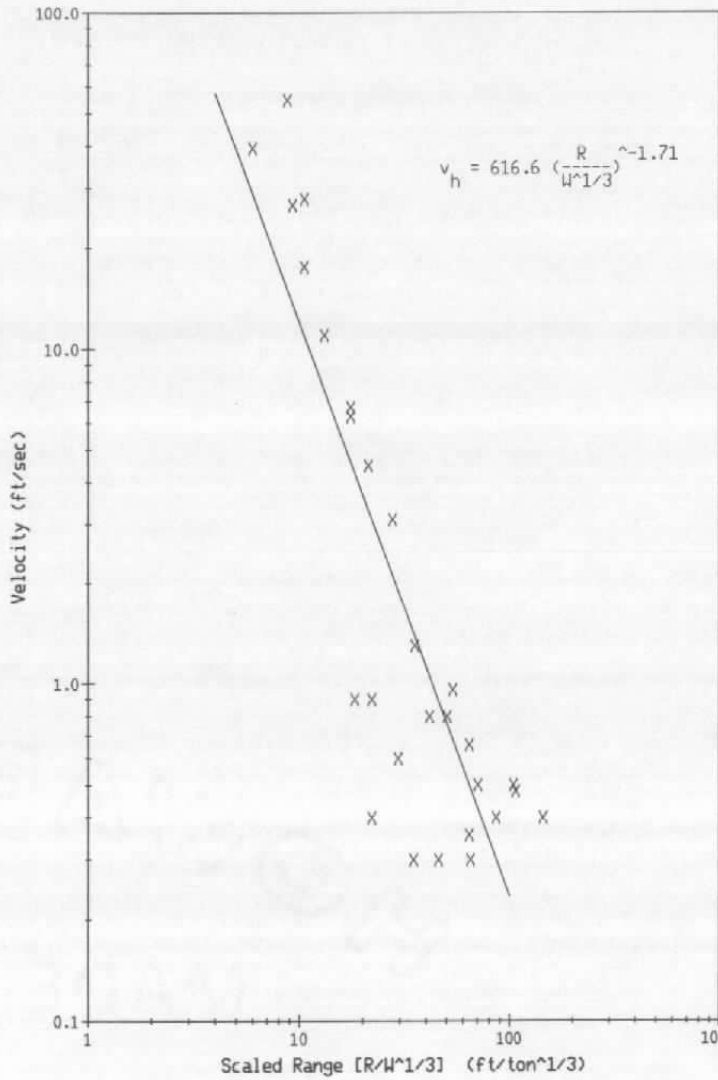

Figure 10. Peak Horizontal Velocity at 10 foot depth, from surface detonation.

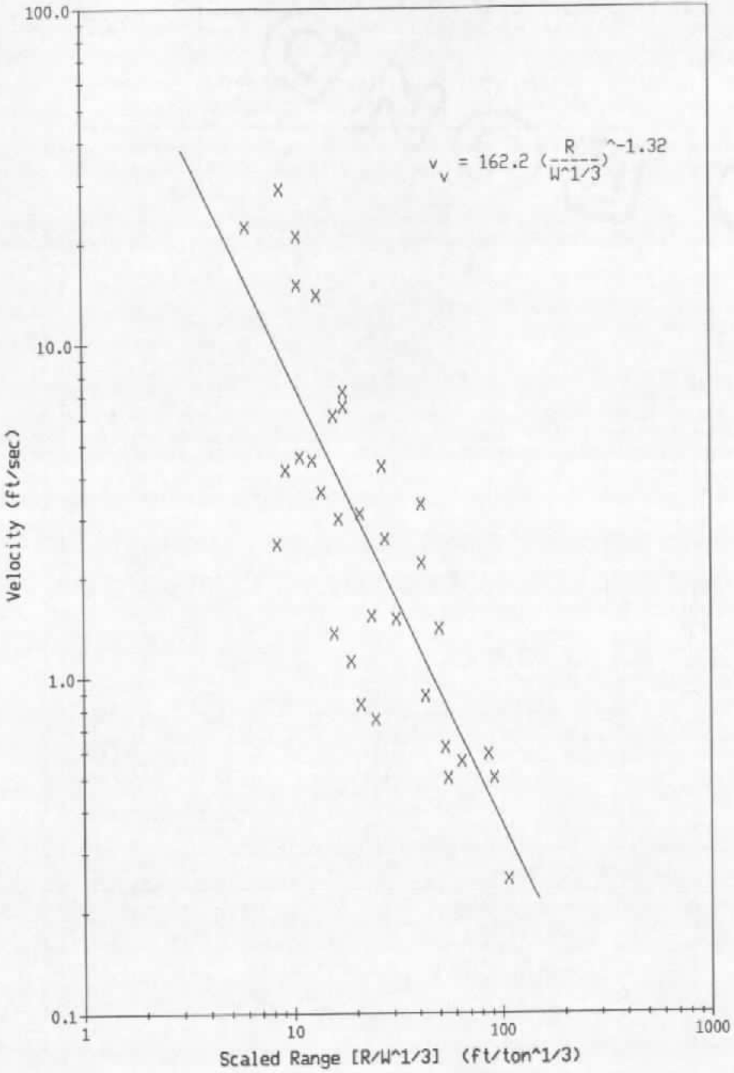

Figure 11. Peak Vertical Velocity at 18 foot depth, from surface detonation.

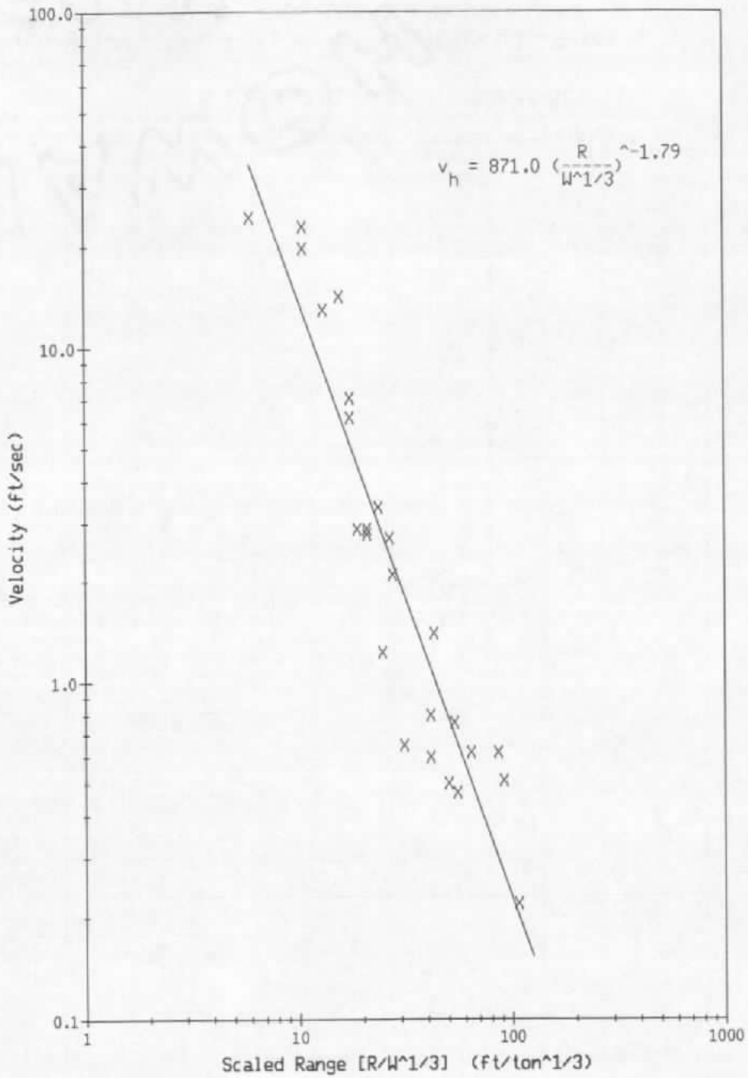

Figure 12. Peak Horizontal Velocity at 18 foot depth, from surface detonation.

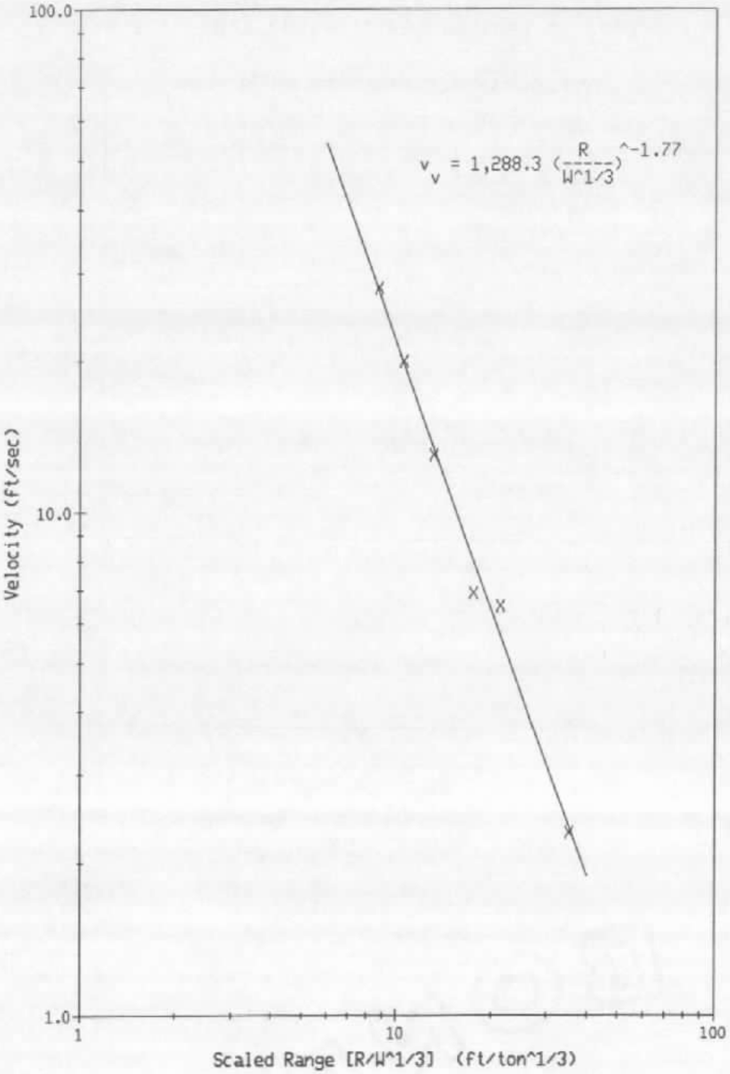

Figure 13. Peak Vertical Velocity at 24 foot depth, from surface detonation.

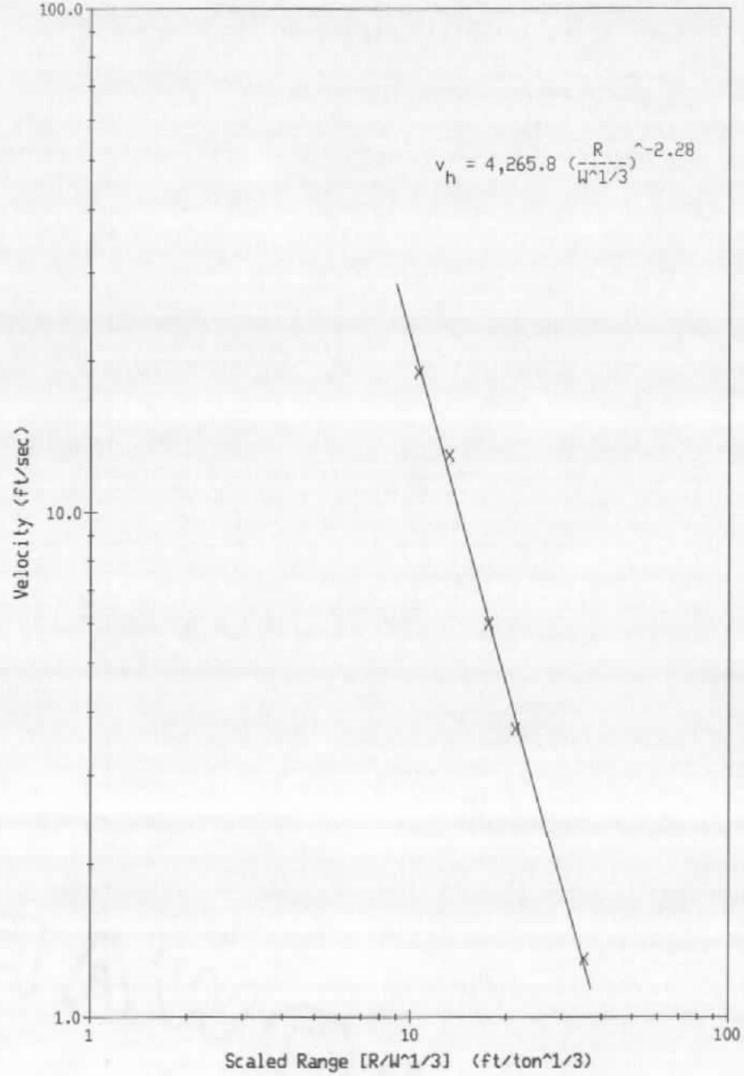

Figure 14. Peak Horizontal Velocity at 24 foot depth, from surface detonation.

Table 2. Peak velocities and associated ranges for a 50T TNT equivalent surface explosion at LRTF.

		RANGE (ft)				
		Surface	5 ft depth	10 ft depth	18 ft depth	24 ft depth
v_v (fps):	15.	76.3	48.9	41.0	22.4	45.6
	10.	100.0	64.3	52.8	30.4	57.3
	5.	158.7	102.3	81.4	51.4	84.8
	4.	184.2	118.9	93.6	60.9	96.2
	3.	223.1	144.2	112.0	75.7	113.2
	2.	292.4	189.3	144.4	102.9	142.3
	1.	464.2	301.4	222.6	174.0	210.6
	.9	497.9	323.4	237.8	188.5	223.5
	.8	538.6	350.0	255.9	206.1	238.9
	.7	588.8	382.9	278.2	228.0	257.6
	.6	652.5	424.6	306.4	256.2	281.0
	.5	736.8	479.9	343.3	294.2	311.5
	.4	855.0	557.4	394.7	348.4	353.4
	.3	1035.7	676.1	472.5	433.2	415.7
	.2	1357.2	887.5	608.7	589.0	522.7
	.15	1644.1	1076.5	728.6	732.4	615.0
	.1	2154.4	1413.2	938.8	995.7	773.3
	.09	2311.2	1516.8	1002.7	1078.5	820.7
	.08	2500.0	1641.6	1079.3	1179.1	877.2
	.07	2732.8	1795.5	1173.2	1304.6	946.0
	.06	3028.5	1991.2	1291.9	1466.3	1032.0
	.05	3240.0	2250.3	1447.8	1683.4	1144.0
	.04	3968.5	2613.9	1664.5	1993.5	1297.7
	.03	4807.5	3170.6	1992.4	2478.9	1526.8
	.02	6299.6	4162.2	2567.0	3370.3	1919.8
	.01	10000.0	6627.6	3958.9	5697.9	2840.1
v_h (fps):	7.5	76.3	50.9	48.5	52.5	59.5
	5.0	100.0	64.9	61.5	65.8	71.1
	2.5	158.7	98.3	92.3	96.9	96.4
	2.0	184.2	112.4	105.2	109.8	106.3
	1.5	223.1	133.5	124.4	128.9	120.6
	1.0	292.4	170.2	157.7	161.7	144.0
	.5	464.2	257.8	236.6	238.2	195.2
	.45	497.9	274.6	251.6	252.6	204.4
	.4	538.6	294.6	269.5	269.8	215.3
	.35	588.8	319.2	291.4	290.7	228.2
	.3	652.5	350.0	318.9	316.9	244.2
	.25	736.8	390.4	354.8	350.9	264.5
	.2	855.0	446.2	404.3	397.4	291.7
	.15	1035.7	530.1	478.3	466.7	331.0
	.1	1357.2	675.8	606.3	585.4	395.4
	.075	1644.1	802.8	717.4	687.4	448.6
	.05	2154.4	1023.4	909.4	862.2	535.9
	.045	2311.2	1090.1	967.2	914.5	561.2
	.04	2500.0	1169.7	1036.1	976.7	591.0
	.035	2732.8	1267.1	1120.3	1052.3	626.6
	.03	3028.5	1389.6	1226.0	1147.0	670.4
	.025	3240.0	1549.9	1363.9	1270.0	726.3
	.02	3968.5	1771.5	1554.0	1438.6	800.9
	.015	4807.5	2104.5	1838.7	1689.4	908.6
	.01	6299.6	2682.9	2330.7	2118.8	1085.5
	.005	10000.0	4063.1	3495.7	3120.9	1471.1

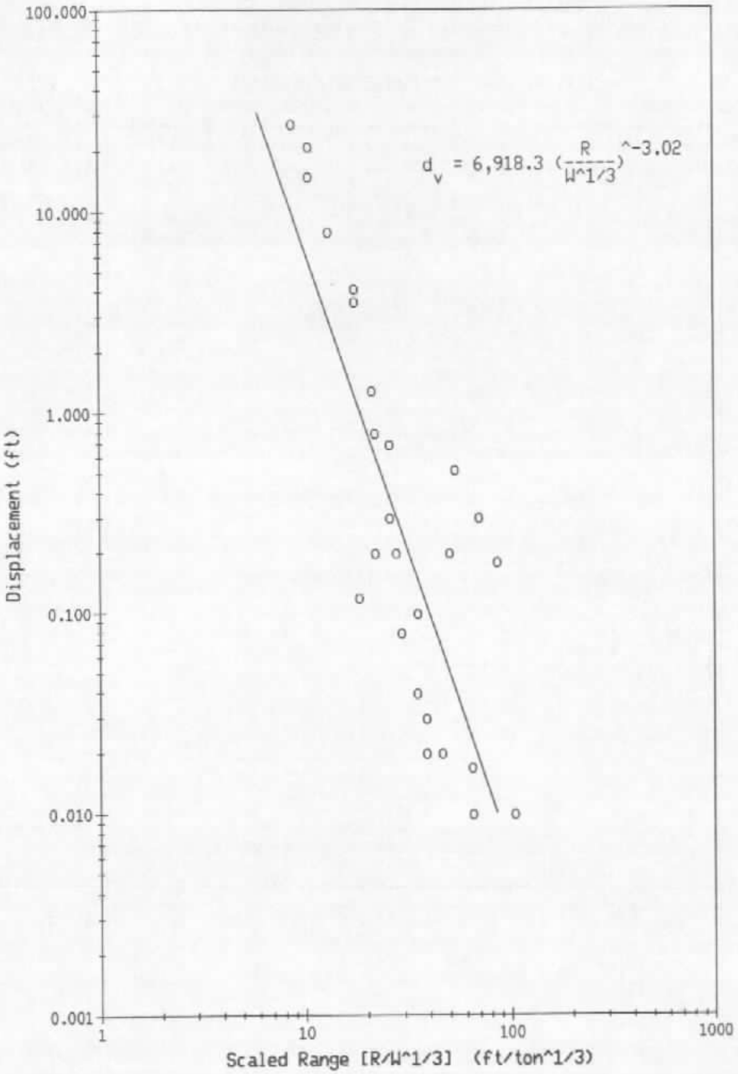

Figure 17. Peak Vertical Displacement at 10 foot depth, from surface detonation.

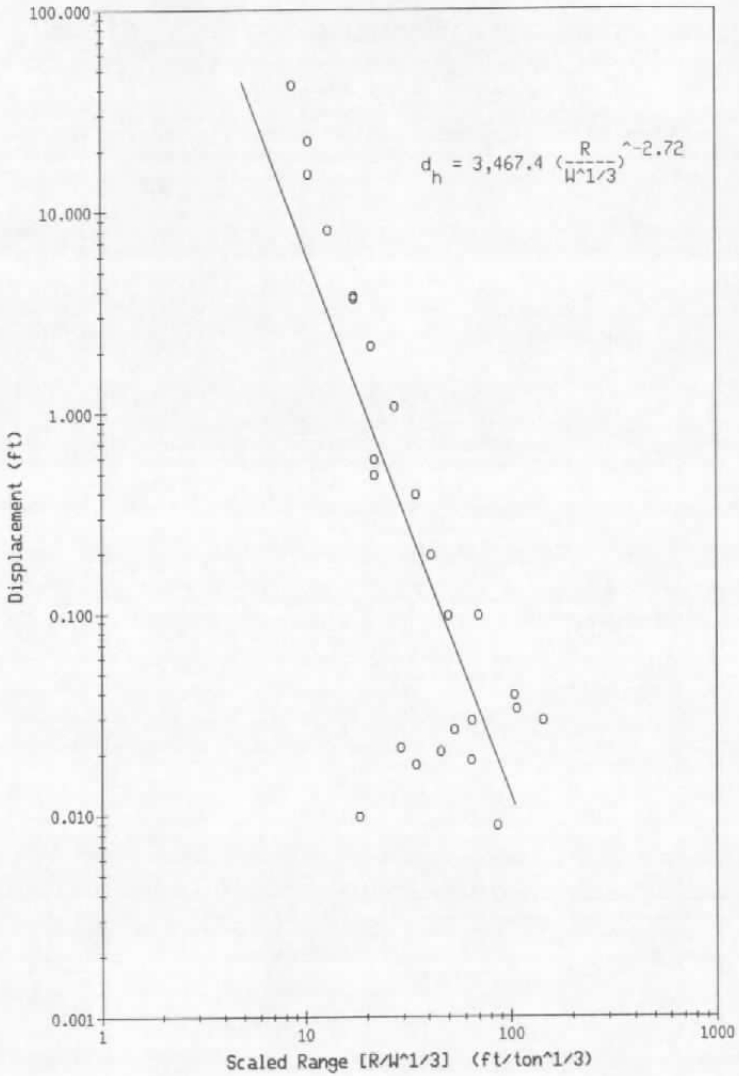

Figure 18. Peak Horizontal Displacement at 10 foot depth, from surface detonation.

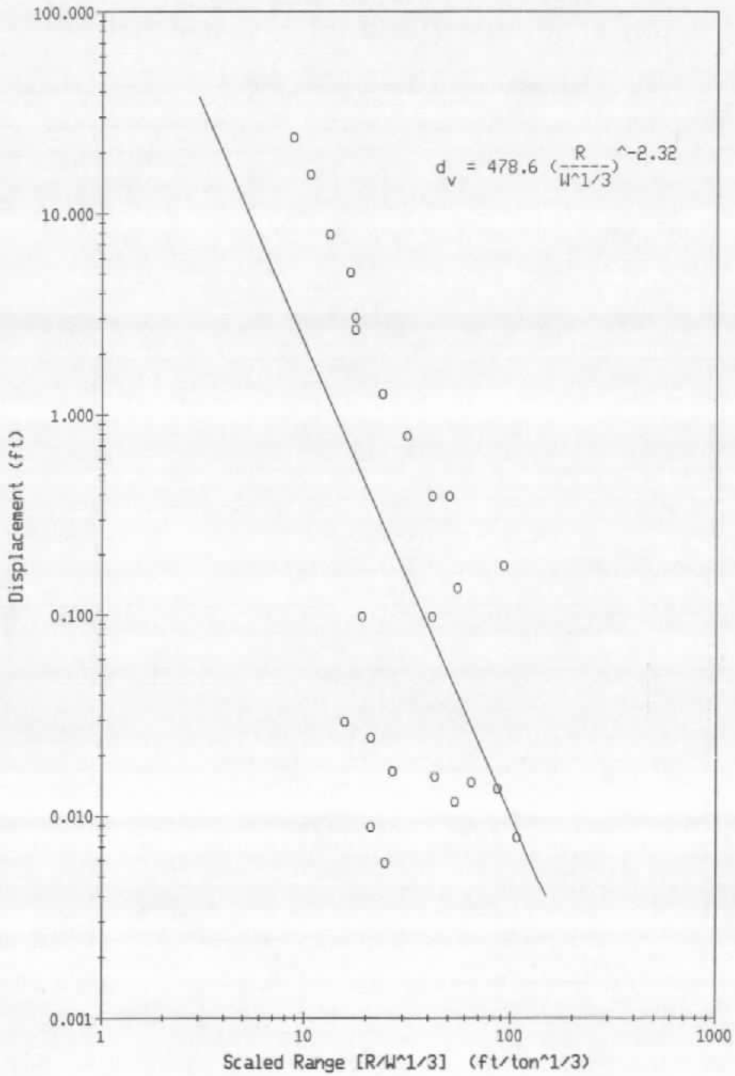

Figure 19. Peak Vertical Displacement at 18 foot depth, from surface detonation.

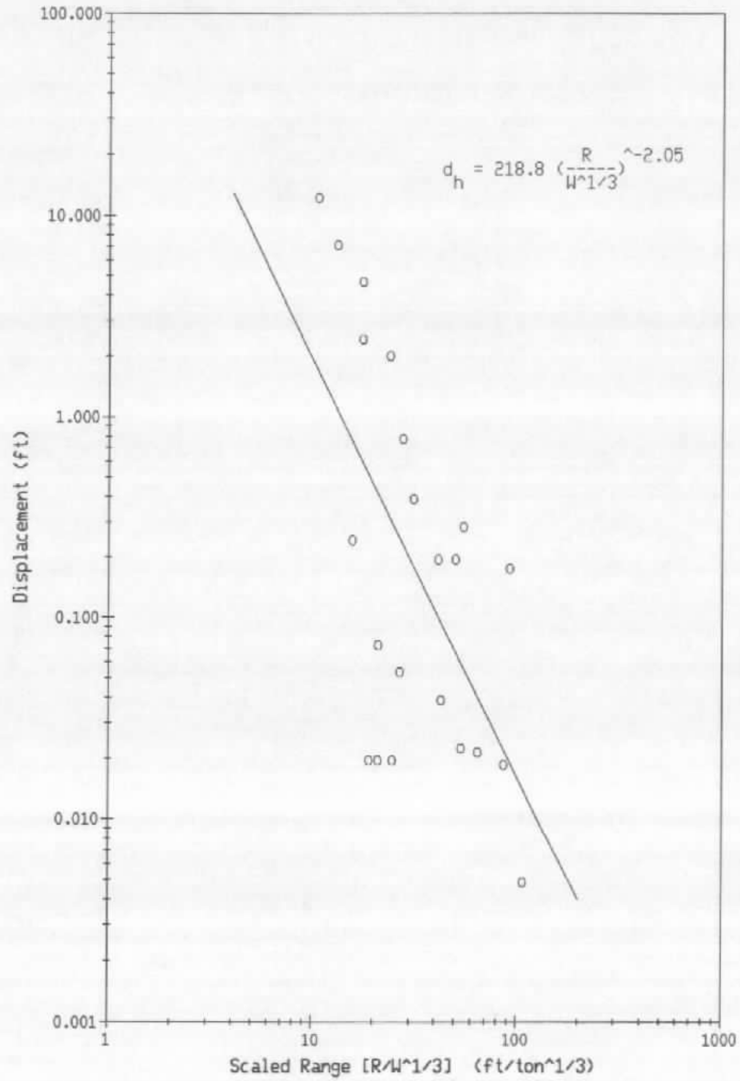

Figure 20. Peak Horizontal Displacement at 18 foot depth, from surface detonation.

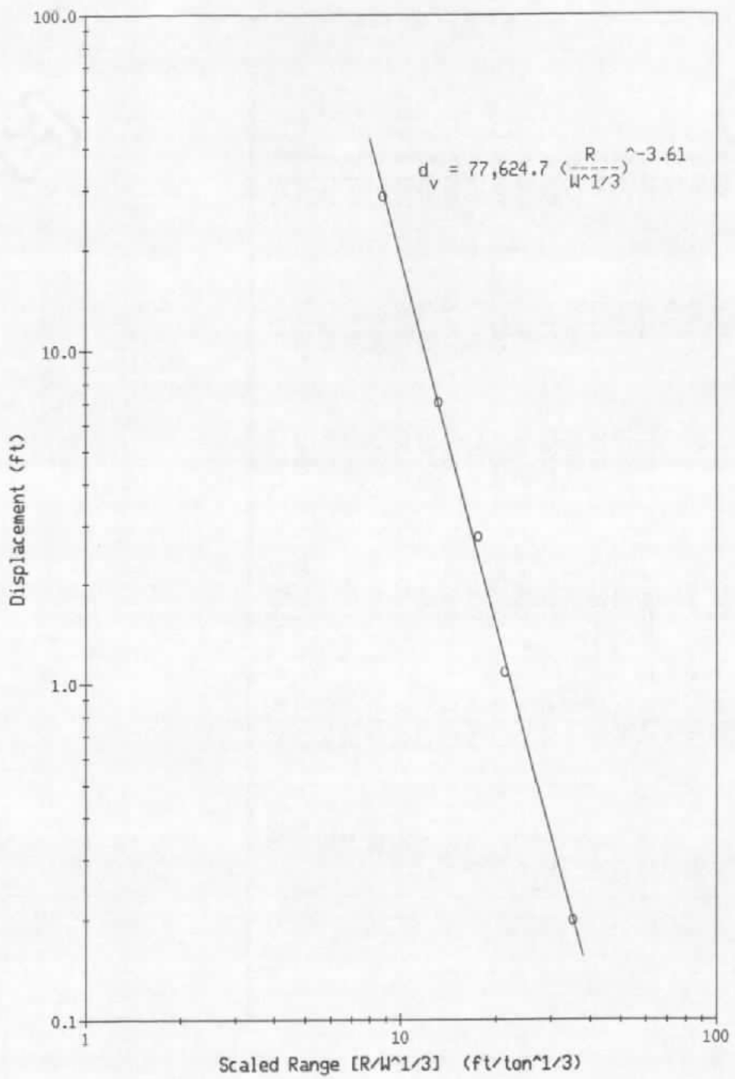

Figure 21. Peak Vertical Displacement at 24 foot depth, from surface detonation.

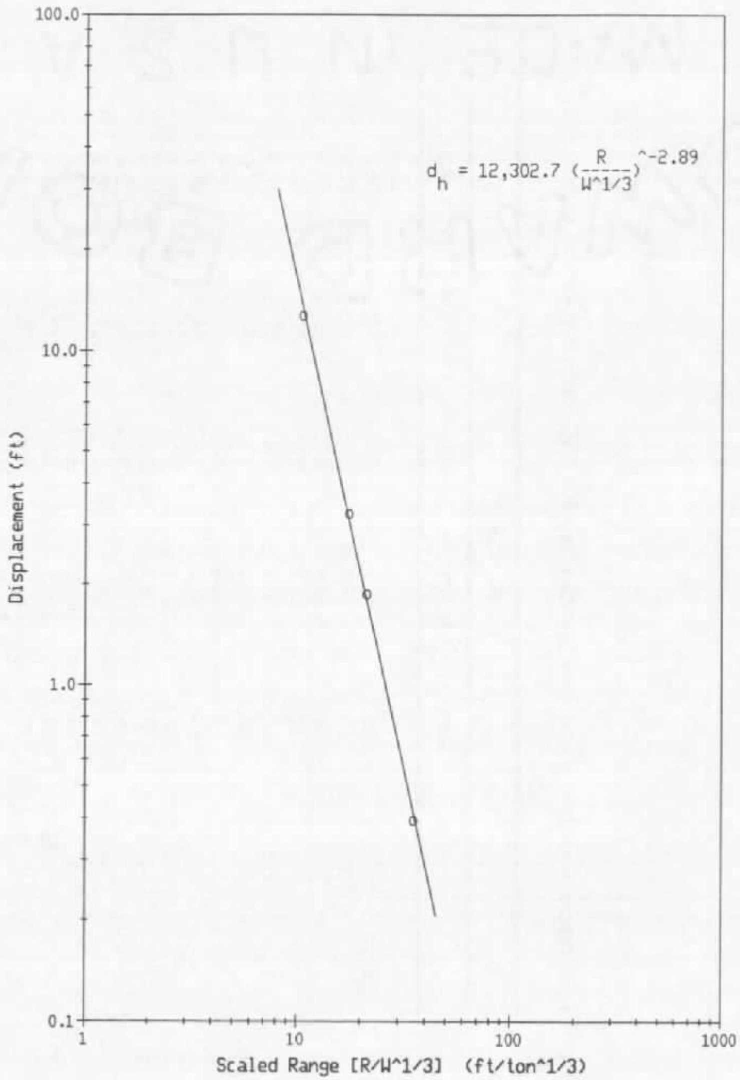

Figure 22. Peak Horizontal Displacement at 24 foot depth, from surface detonation.

Table 3. Peak displacements and associated ranges for a 50T TNT equivalent surface explosion at LRTF.

		RANGE (ft)				
		Surface	5 ft depth	10 ft depth	18 ft depth	24 ft depth
d_v (in):	300.	24.2	24.6	23.7	13.2	34.2
	150.	31.0	31.4	29.8	17.7	41.4
	75.	39.7	40.1	37.5	23.9	50.2
	50.	45.9	46.2	42.8	28.4	56.0
	25.	58.8	58.8	53.8	38.2	67.9
	20.	63.7	63.3	57.7	41.9	72.0
	15.	70.6	70.5	63.9	47.8	78.4
	10.	81.6	82.4	74.1	58.0	88.7
	5.	104.5	105.1	93.2	78.2	107.4
	4.	113.1	116.3	102.6	88.5	116.3
	3.	125.4	124.0	108.9	95.7	122.4
	2.	144.9	134.1	117.3	105.4	130.2
	1.	185.6	184.9	158.9	156.4	167.8
	.75	205.7	204.6	174.8	177.1	181.7
	.50	237.7	235.8	199.9	210.9	203.3
	.25	304.5	300.8	251.4	284.3	246.3
	.15	365.5	383.6	316.3	383.3	298.5
	.05	541.0	529.0	428.4	569.0	384.7
	.025	693.0	674.7	538.9	767.1	466.2
	.005	1231.3	2662.3	918.3	1535.1	728.0
d_h (in):	300.	24.2	24.9	22.6	10.6	31.5
	150.	31.0	32.0	29.1	14.9	40.0
	75.	39.7	41.2	37.6	20.9	50.8
	50.	45.9	47.8	43.5	25.3	58.3
	25.	58.8	61.4	56.1	35.5	74.1
	20.	63.7	66.3	60.7	39.4	79.8
	15.	70.6	74.2	67.9	45.8	88.7
	10.	81.6	87.3	80.1	56.9	103.5
	5.	104.5	112.5	103.3	79.8	131.6
	4.	113.1	124.9	114.8	91.8	145.4
	3.	125.4	133.5	122.8	100.3	154.8
	2.	144.9	144.8	133.3	111.9	167.3
	1.	185.6	202.3	186.7	174.9	229.7
	.75	205.7	224.7	207.5	201.3	253.7
	.50	237.7	260.6	240.8	245.3	291.9
	.25	304.5	335.6	310.8	344.0	371.0
	.15	365.5	432.2	400.9	482.4	471.6
	.05	541.0	603.8	561.6	754.2	647.6
	.025	693.0	777.6	724.5	1057.7	823.1
	.005	1231.3	3242.1	1309.3	2319.1	1436.5

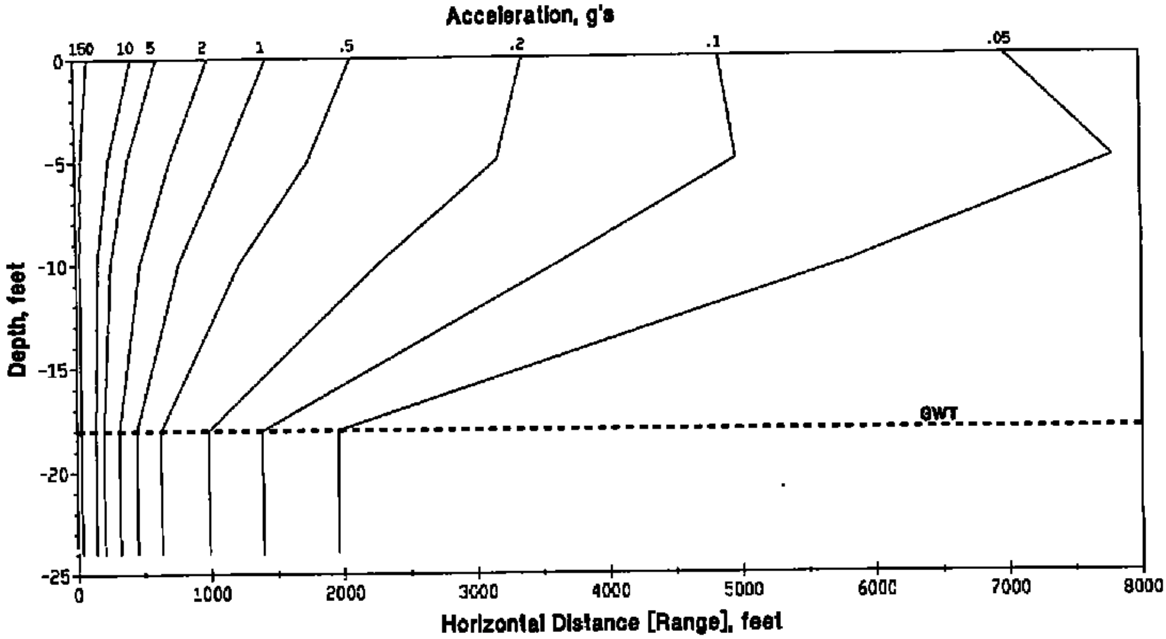

Figure 23. Peak Vertical Acceleration profile (in g's).

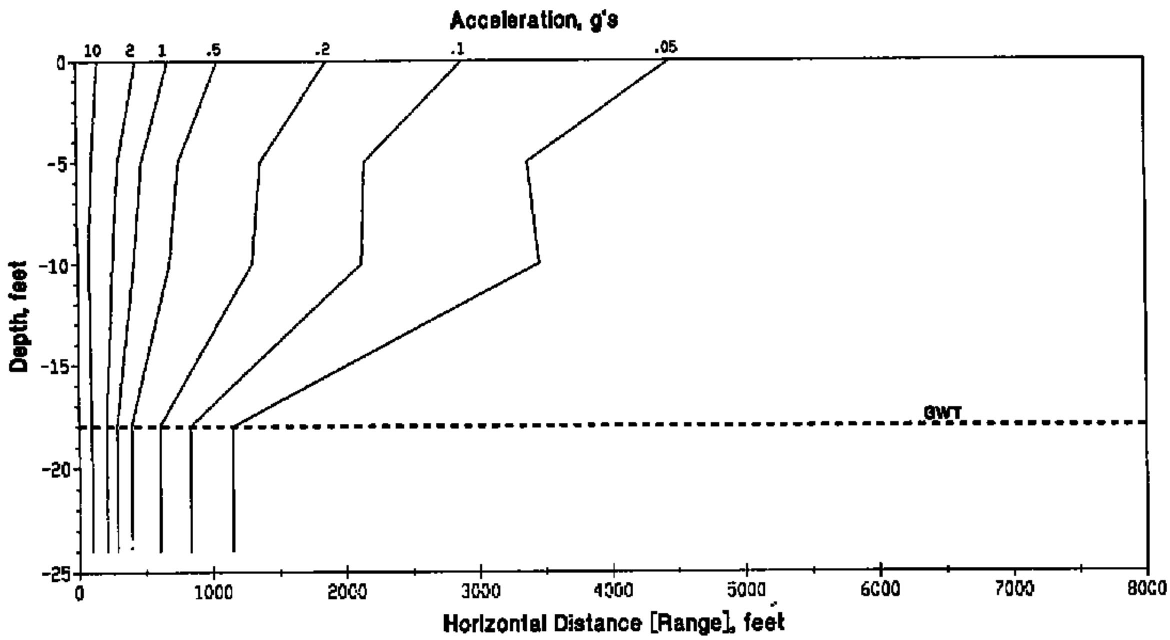

Figure 24. Peak Horizontal Acceleration profile (in g's).

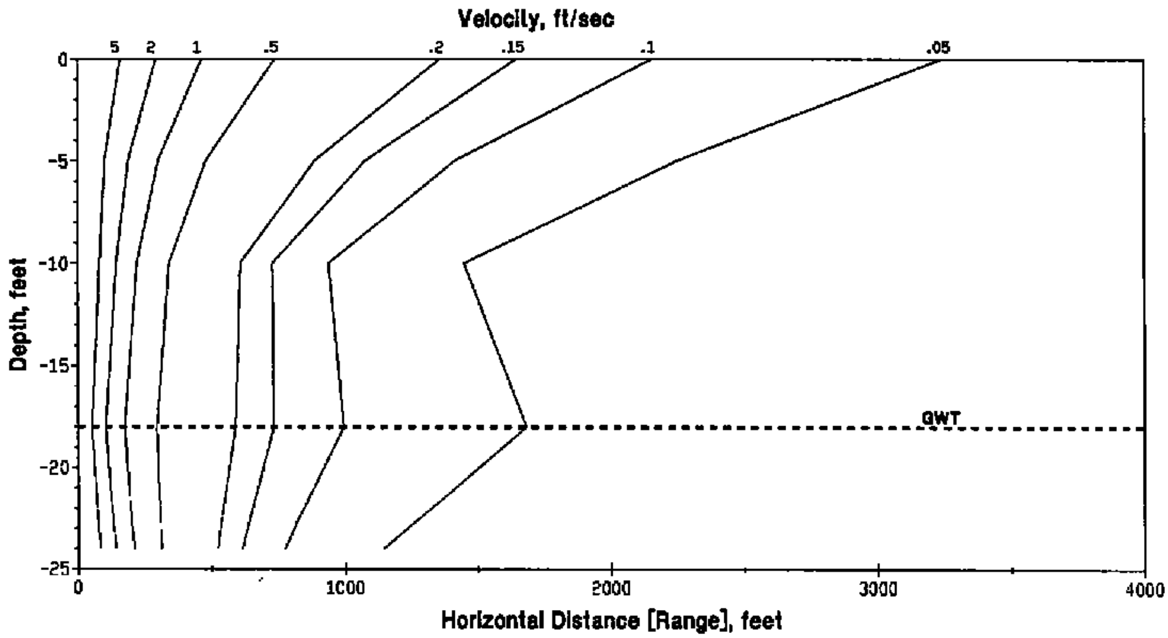

Figure 25. Peak Vertical Velocity profile (in ft/sec).

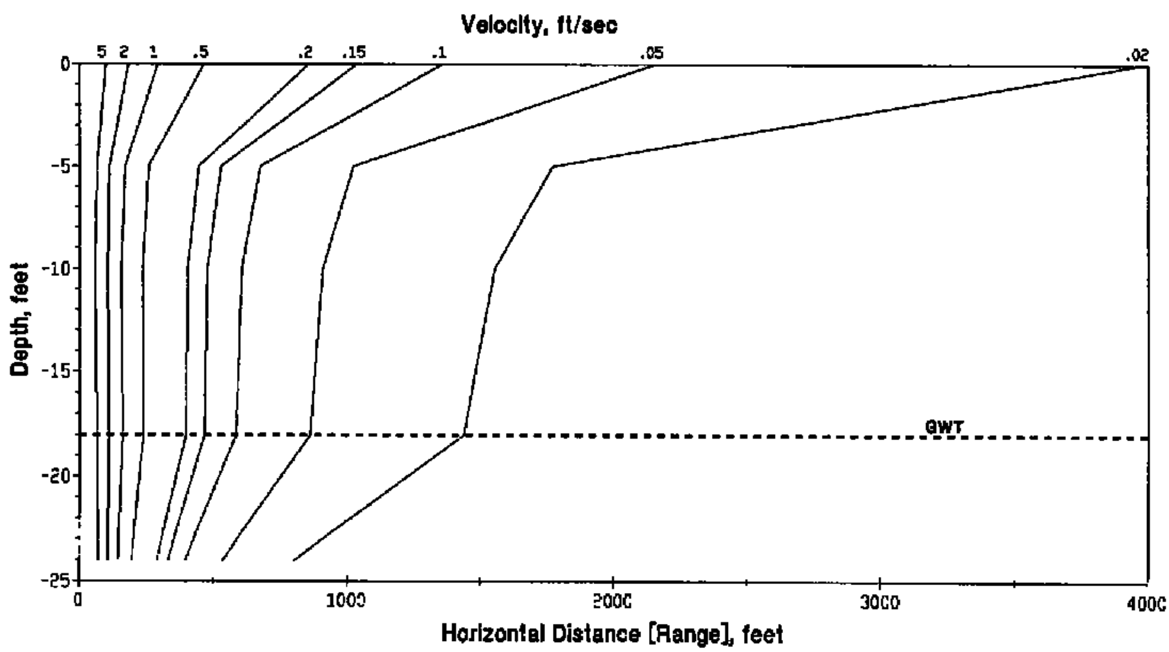

Figure 26. Peak Horizontal Velocity profile (in ft/sec).

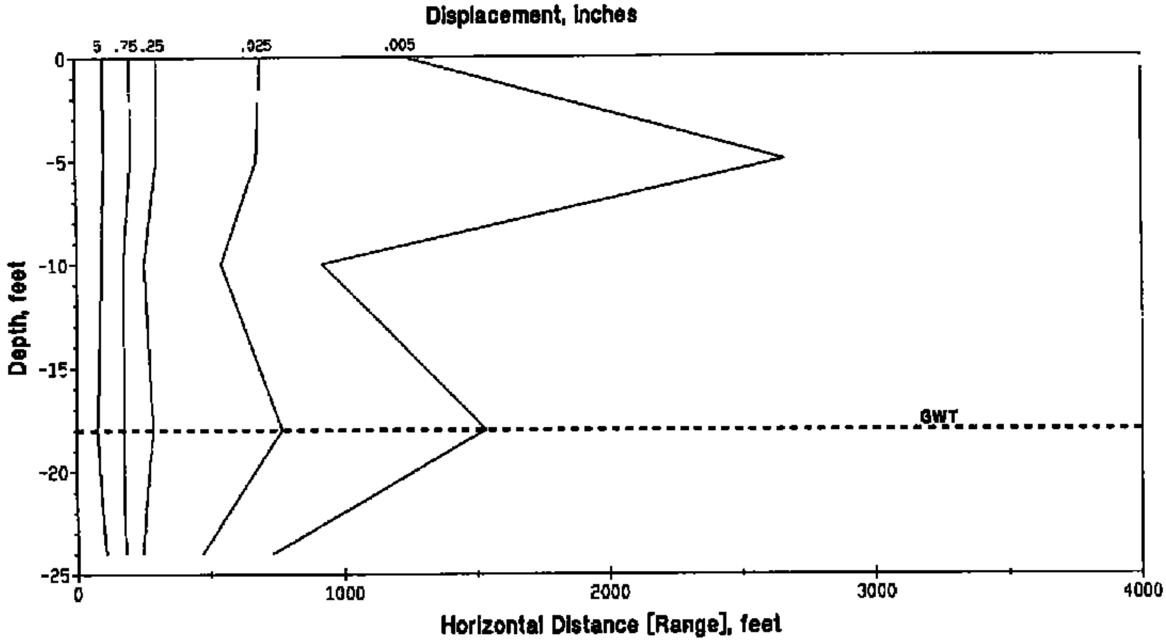

Figure 27. Peak Vertical Displacement profile (in inches).

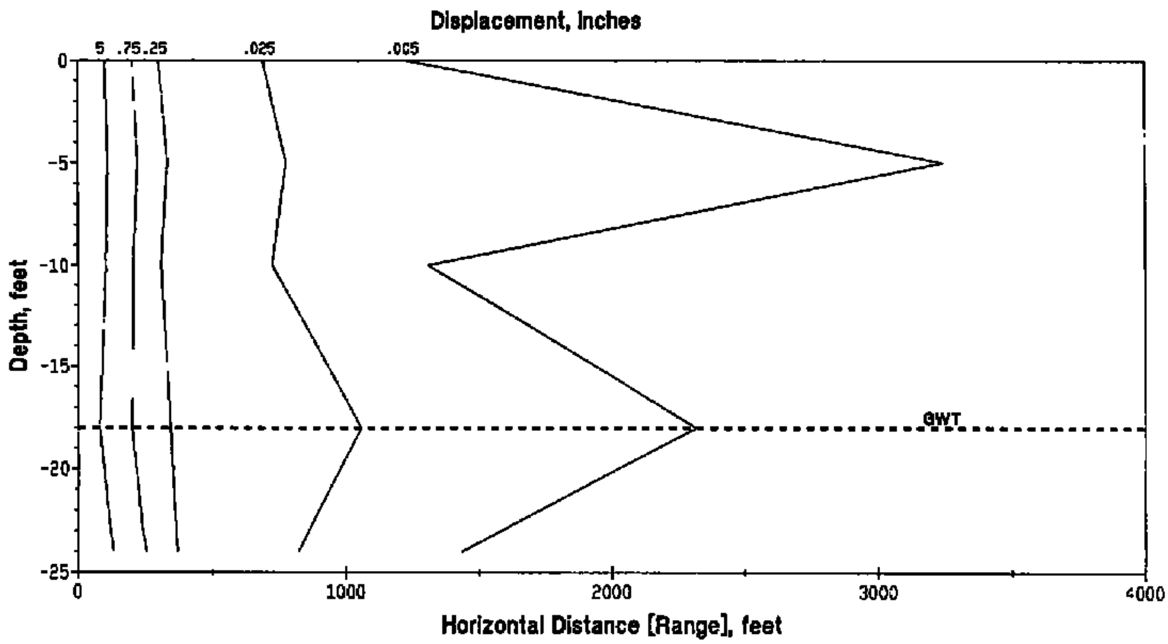

Figure 28. Peak Horizontal Displacement profile (in inches).

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